

New Generation Stellar Physics: Asteroseismology & Virtual Observatory

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In the last years we have witnessed a dramatic change in the research infrastructures: Advances in communication networks, computational resources and data storage devices are fostering new and more efficient science. In this new scenario, the Virtual Observatory (VO) is the framework where a new methodology for astronomical research is being built. This poster shows the natural connection between Asteroseismology and VO. We describe the current status of a project developed by the Spanish Virtual Observatory in which, for the first time, asteroseismic models together with visualization tools for asteroseismology are managed within VO.

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1 Introduction

The twentieth century has provided an important qualitative and quantitative leap in the development of science and technology. The perfect symbiosis between the two has opened new horizons in the knowledge of nature: from the study of the fundamental components of matter, through life sciences, to better understand of the origin and evolution of the Universe and its components, like galaxies, stars, planets, to name a few.

In the last decades we have witnessed a significant progress of Stellar Physics, largely due to the development of its great laboratory: the stellar seismology (also known as asteroseismology). Today, several space missions have been designed to study the interior of stars and search for extra-solar planets like MOST (Matthews et al. 1998), CoRoT (Baglin et al. 2003), or Kepler (Gilliland et al. 2010) and some others are in preparation like PLATO (Catala 2009). Besides this, several precision instruments are being used for the first time for asteroseismology (CRIRES, UVES, FOCES, FEROS, HARPS) and others are currently in phase of development: NAHUAL (Martín et al. 2005), GIANO (Oliva et al. 2006), CARMENES (Quirrenbach et al. 2009), etc.

Moreover, one of the great revolutions in data transmission is undoubtedly the emergence of the Internet and its boundless possibilities. Day after day, new Internet-based technologies such as Web, Web 2.0, social networks, etc. come up with new useful tools. In astrophysics, this break-

through has its own name: the Virtual Observatory¹ (VO). Today, this tool allows us to handle hundreds of terabytes in a single click, and access to thousands of astronomy databases interlinked through a single web portal.

We present a new generation tool for stellar physics: the fusion of Virtual Observatory technologies with asteroseismology. The result is a tool conceived to easily handle observations and models in the framework of the large research programs like the above mentioned space missions. We seek to offer to the community a tool from which users have access to very different models without building interfaces, easily find models representative of the studied stars, and even compare online global and shell physical variables of a selection of models.

2 The project details

The official name of the project (the name of the tool is to be defined) is "Development of a VO-tool for asteroseismic models". It is currently under development within the Spanish Virtual Observatory Project² (SVO).

The staff is composed by four researchers: A. Moya, A. García Hernández, E. Solano (project manager) and J.C. Suárez (principal investigator), and one technician (C. Rodrigo), from two institutions: the Instituto de Astrofísica de Andalucía (IAA-CSIC), and the Centro de Astrobiología (CAB-INTA-CSIC).

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¹ <http://ivoa.net/>

² <http://svo.cab.inta-csic.es/>

Presently, around $5 \cdot 10^5$ asteroseismic models are implemented in the tool. These have been computed using three different codes:

- The evolutionary code CESAM (Morel 1997) which provides the equilibrium models.
- The FILOU code (Suárez 2002; Suárez, Goupil & Morel 2006; Suárez & Goupil 2008) which provides adiabatic oscillations corrected for the effect of rotation.
- The GraCo code (Moya et al. 2004; Moya & Garrido 2008a).

This VO service is flexible enough to incorporate, in the future, other collections coming from different codes and/or databases that might be of interest for other groups.

We have implemented in the tool the following technical services

- A S3 server for each code³.
- A web application using the S3 services to find, select and analyze data⁴.
- The first *data model* for asteroseismic data⁵.

The data model mentioned above consists in 17 stellar global properties (e.g. effective temperature, surface gravity, luminosity, etc.), 44 star shell variables (e.g. density, pressure, temperature, etc.), and 35 seismic properties (e.g. frequency ranges, fundamental radial mode, large separation, etc.). These correspond to input criteria that can be queried simultaneously to the tool database service (see Fig. 1) in order to find all the models in the databases selected by the user.

Figure 2 illustrates the results yield by the tool, given some inputs parameters queried by the user. This include information on the number of *valid* results, i.e. the number of models matching the input criteria, the common values (databases might be very heterogenous, so common physical parameters provide an idea of which variables are simultaneously shared by all the models), and the list of valid models. This list contains some useful variables, like mass, metallicity, effective temperature, surface gravity, etc. Models can be sorted by any of these variables. Moreover, it is possible to visualize and/or download each of the selected models together with the model track they belong to⁶.

For all the valid models yield by the tool, it is possible to make diagrams with global and shell variables. An example of a plot with global variables is the HR diagram shown in Fig. 3. Plots are flexible and allow modification of scales (e.g. for zooming and/or using a logarithmic scale) and variables. Moreover, interactive shell variable plots are also implemented. These consist in diagrams of in-shell variables (i.e. variables varying with the model shell, for instance with the stellar radius), in which the user can compare the behavior of such variables for different selected models (see e.g. Fig. 4).

³ <http://svo.cab.inta-csic.es/theory/sisms3>

⁴ <http://svo.cab.inta-csic.es/theory/sisms3/>

⁵ <http://svo.cab.inta-csic.es/theory/sisms3/concepts.php>

⁶ Databases are constructed by including model evolutionary tracks. For each of the models of the tracks, the oscillation spectrum is also provided.

Fig. 1 Snapshot of the web user interface in which the user provides input parameters for search queries. Global stellar parameters together with equilibrium model physical parameters (left column), and pulsation variables (right column). Prior to this interface, the user has previously selected the model databases in which the tool will send the user queries.

Fig. 2 Snapshot with an illustration of the outputs shown by the tool with the models matching all the input criteria simultaneously. On top, a table summarizes the common parameters/variables to all the resulting models, and the number of *valid* models, i.e. those matching all the user-defined input criteria simultaneously. VOTables and complete models can be downloaded, in complete tracks or individually by selecting them in the results table. From this interface, models can be marked to be analyzed with visualization tools.

To summarize, the main characteristics of this VO tool are:

- Efficiency. The VO tool queries multiple model databases in seconds.
- Collections of models are handled easily and with user-friendly web interfaces.
- The only software required is a web browser with JavaScript.
- Tables, figures, and model collections are fully downloadable.

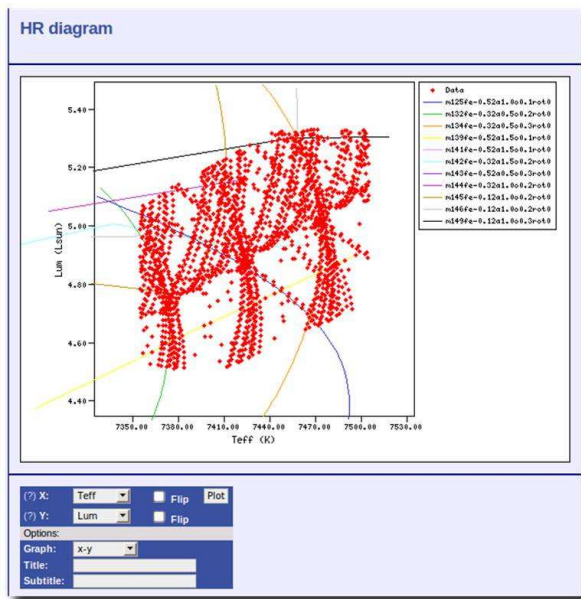


Fig. 3 Snapshot with an illustration of a Hertzsprung-Russell diagram of the models matching all the input criteria simultaneously. Dots correspond to the effective temperature and luminosity of all the valid models, and lines represent some of the selected evolutionary tracks.

- Designed for the easy and rapid comparison of very different and heterogeneous models.
- Visualization tools are available
- The tool offers new scientific potential.

The possibility of managing a huge amount of models, their online comparison and visualization, opens new possibilities in the research itself. For instance, the user of this tool will be able to search for general properties in very different and heterogeneous databases, to make statistics, or simply focus in the science, instead of spending a significant amount of time building interfaces, dealing with formats, writing codes for plotting results, etc. An example of application is the recently comparison (Moya et al. 2008b) of oscillation codes undertaken within the scientific exploitation of the asteroseismic space mission *CoRoT*.

3 Future prospects

The present VO tool will be *see the web light* during this year. This will be done in a scientific publication with peer review. To do so, we are currently preparing a scientific case, which is mainly based on oscillation mode statistics for intermediate-mass, main-sequence stars (see, for instance, García-Hernández et al. 2009, Poretti et al. 2009).

Then, once the tool is published, we will initiate a contact round with research groups interested in adapting their model databases to VO.

From the point of view of technical implementation, it is envisaged to link directly observational input parameters

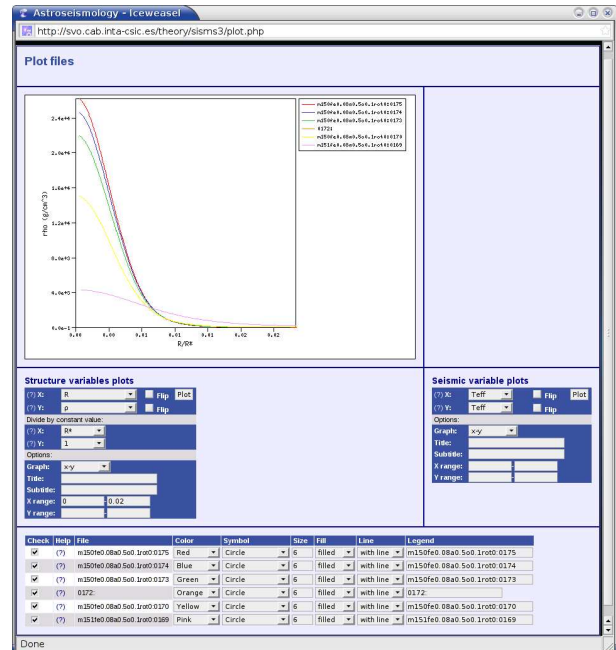


Fig. 4 Snapshot with an illustration of a shell-variable type diagram of the models matching all the input criteria simultaneously. In particular, this diagram depicts the variation of the density (in c.g.s.) as a function of the radial distance normalized to the stellar radius.

from other VO tools. This will empower the tool for the use with large scientific programs producing lots of data, like space missions.

In what regards the modeling, we are currently studying the possibility of linking this tool with GRID computing-based technology, and the use of genetic algorithms.

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